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Seawater desalination:

Current trends and challenges

Changing climate patterns, population growth pressures and the limited availability of new and inexpensive fresh water supplies are shifting the water industry's attention. In an emerging trend, the world is reaching to the ocean for fresh water. Nikolay Voutchkov from Water Globe Consulting explains recent trends and explains his predictions for the future market.

Until recently, seawater desalination was limited to desert-climate dominated regions. Technological advances, and an associated decrease in water production costs over the past decade, have expanded its use in coastal areas traditionally supplied with fresh water resources. Today, desalination plants provide approximately 1% of the world's drinking water supply and this percentage has been increasing exponentially for the past ten years [1], (See Figure 1). Seawater desalination is the fastest growing sector of this market. More than US$10 billion of investment in the next five years is projected to add 10,510 MGD of new desalination plant production capacity worldwide. This capacity is expected to double by the year 2020.

Two basic types of technologies have been widely used to separate salts from ocean water: thermal evaporation and membrane separation. Over the past ten years, seawater desalination using semi-permeable seawater reverse osmosis (SWRO) membranes has gained momentum and currently dominates desalination markets outside of the Middle Eastern region. Here, thermal evaporation is still the desalination technology of choice (mainly due to access to lower-cost fuel and traditional use of facilities co-generating power and water).

A clear recent trend in seawater desalination is the construction of larger capacity plants, which deliver an increasingly greater portion of the fresh water supply of coastal cities around the globe. Most of the large desalination plants built between 2000 and 2005 were typically designed to supply only 5-10% of the drinking water for large coastal urban centres. Today, most regional or national desalination project programmes in countries such as Spain, Australia, Israel, Algeria and Singapore, aim to secure 20-25% of their long-term drinking water needs with desalinated seawater.

Technology advances

High productivity elements

A key factor which has contributed to the dramatic decrease of seawater desalination costs over the past ten years is the advancement of the SWRO membrane technology. Today's high-productivity membrane elements are designed with several features which yield more fresh water per membrane element than at any time in the recent history of this technology: higher surface area, enhanced permeability and denser membrane packing. Increasing active membrane leaf surface area and permeability allows it to gain significant productivity using the same size (diameter) membrane element. Active surface area of the membrane elements is typically increased by membrane production process automation, denser membrane leaf packing and by adding membrane leafs within the same element.

The total active surface area in a membrane element is also increased by increasing

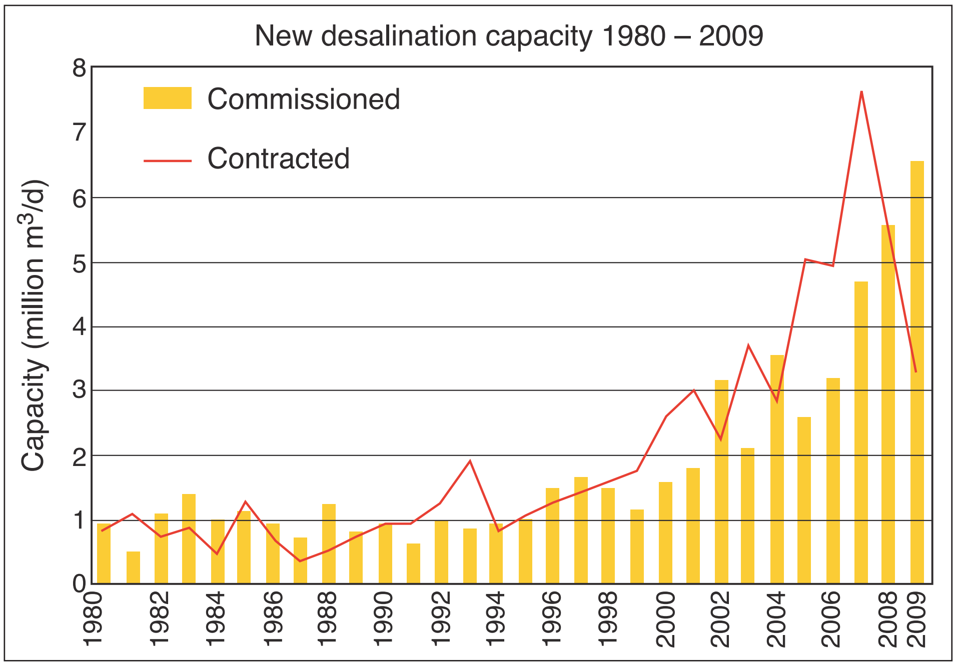

Figure 1. Thirty-year world desalination capacity trend. (Source: GWI, 2009; Note: 1 million m^3/day = 264.2 MGD).

membrane size/diameter. Although 8 inch SWRO membrane elements are still the 'standard' size most widely used in full-scale applications, larger 16 inch and 18 inch size SWRO membrane elements have become commercially available over the past three years, and have already found full-scale implementation in several SWRO projects worldwide [2].

In the second half of the 1990s, the typical 8 inch SWRO membrane element had a standard productivity of 5,000 to 6,000 gallons per day (gpd) at a salt rejection of 99.6%. In 2003, several membrane manufacturers introduced high-productivity seawater membrane elements which are capable of producing 7,500 gpd at a salt rejection of 99.75%. Just one year later, even higher productivity (9,000 gpd at 99.7% rejection) seawater membrane elements were released on the market. Over the past three years SWRO membrane elements combining a productivity of 10,000 to 12,000 gpd with high-salinity rejection have become commercially available and are now gaining wider project implementation.

The newest membrane elements provide flexibility and choice and allow users to trade productivity and pressure/power costs. The same water product quality goals can be achieved in one of two general approaches: (1) reducing the system footprint/construction costs by designing the system at higher productivity, or (2) reducing the system's overall power demand by using more membrane elements, designing the system at lower flux and recovery, and taking advantage of new energy recovery technologies which further minimize energy use if the system is operated at lower (35% to 45%) recoveries.

Innovative hybrid membrane configuration combining SWRO elements of different productivity and rejection within the same vessel, which are sequenced to optimize the use of energy introduced with the feed water to the desalination vessels, is also finding wider implementation. In addition, a number of novel membrane SWRO train configurations have been developed over the past five years aiming to gain optimum energy use and to reduce capital costs for production of high-quality desalinated water.

Enhancements for lower energy use

Energy is one of the largest expenditures associated with seawater desalination. Figure 2 shows a distribution of the energy use within a typical seawater desalination plant. As shown on this figure, the SWRO system typically uses more than 70% of the total plant energy. The second area of large energy use is often the product water delivery to the distribution system. Typical seawater desalination plant would be located within 5-10 miles from the ultimate points of desalinated water delivery to the final users. However, in some projects, where environmental considerations and public acceptance dictate selecting plant location further away from the distribution system, energy use for product water delivery may become a significant portion (10% to 30%) of the total project energy demand. Under these circumstances, building fewer small size plants may become more viable and cost effective.

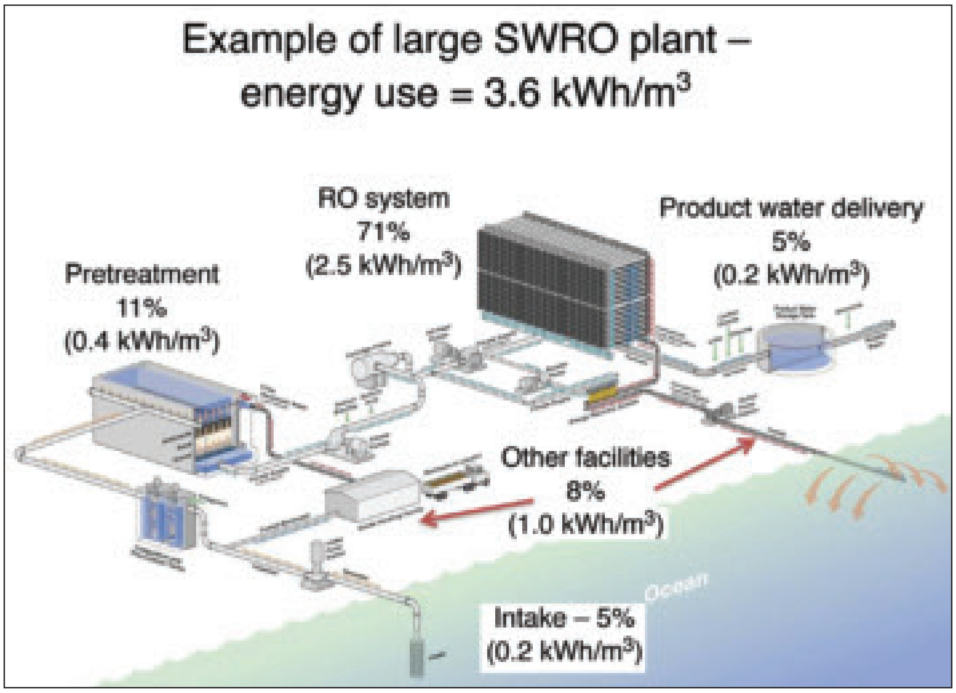

Figure 2. Energy use breakdown of typical SWRO desalination plant.

High pressure pump efficiency

An approach for reducing total RO system energy use which is widely applied throughout the desalination industry is to incorporate larger, higher efficiency centrifugal pumps which serve multiple RO trains. This trend stems from the fact that the efficiency of multistage centrifugal pumps increases with their size (pumping capacity). For example, under a typical configuration where an individual pump is dedicated to each desalination plant RO train, high pressure pump efficiency is usually in a range of 80-83%. However, if the RO system configuration is such that a single high pressure pump is designed to service two RO trains of the same size, the efficiency of the high pressure pumps could be increased by up to 85%.

Proven design which takes this principle to the practical limit of centrifugal pump efficiency (≈ 90%) is implemented at the 86 MGD Ashkelon seawater desalination plant in Israel. Two duty horizontally split high pressure pumps are designed to deliver feed seawater to 16 SWRO trains at a guaranteed long term efficiency of 88%. Continuous plant operational track record over the past five years shows that the actual efficiency level of these pumps under this configuration is closer to 90%.

A current trend for smaller desalination facilities (plants with fresh water production capacity of 250,000 gpd or less) is to use positive displacement (multiple-piston) high-pressure pumps and energy recovery devices, which are often combined into a single unit. These systems are configured to take advantage of the high efficiency of the positive displacement technology which practically can reach 94-97%.

Improved energy recovery

Advances in the technology and equipment allowing the recovery and reuse of energy applied for seawater desalination, have resulted in a reduction of 80% of the energy used for water production over the last 20 years. Today, the energy needed to produce fresh water from seawater for one household per year (~2,000 kW/yr) is less than that used by the same household's refrigerator.

While five years ago, the majority of the existing seawater desalination plants used Pelton Wheel-based technology to recover energy from the SWRO concentrate, today the pressure exchanger-based energy recovery systems dominate in most desalination facility designs. The key feature of this technology is that the energy of the SWRO system concentrate is directly applied to pistons which pump intake seawater into the system. Pressure-exchanger technology typically yields 5-15% higher energy recovery savings than the Pelton-Wheel-based systems.

Figure 3 depicts the configuration of a typical pressure exchanger-based energy recovery system. After membrane separation, most of the energy applied for desalination is contained in the concentrated stream (brine) which also contains the salts removed from the seawater. This energy-bearing stream (shown with red arrows on Figure 3) is applied to the

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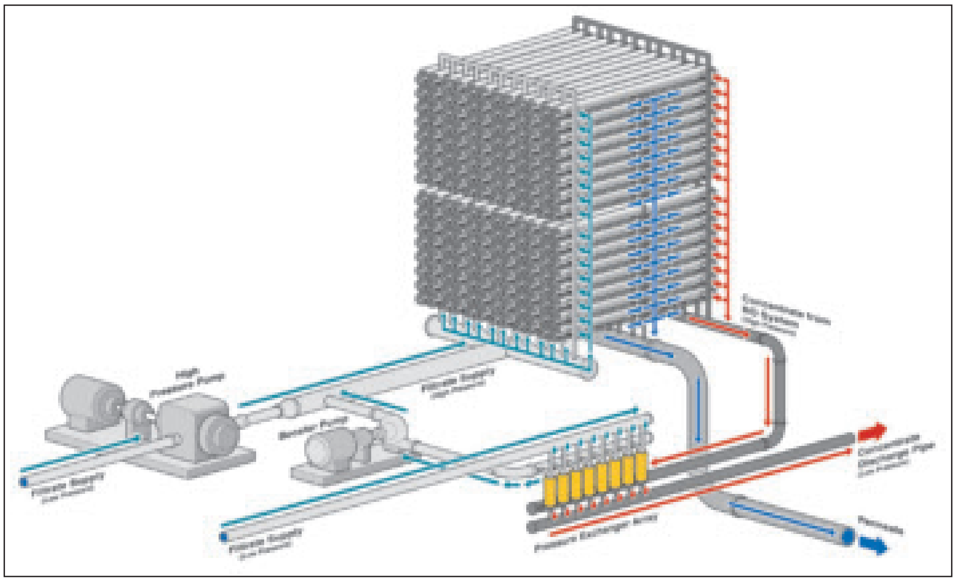

Figure 3. Pressure exchanger energy recovery system.

back side of pistons of cylindrical isobaric chambers, also known as pressure exchangers (shown as yellow cylinders on Figure 3). These pistons pump approximately 45-50% of the total volume of seawater fed into the RO membranes for salt separation. Since a small amount of energy (4-6%) is lost during the energy transfer from the concentrate to the feed water, this energy is added back to feed flow by small booster pumps to cover for the energy loss. The remainder (45-50%) of the feed flow is handled by high-pressure centrifugal pumps. Harnessing, transferring and reusing the energy applied for salt separation at very high efficiency (94-96%) by the pressure exchangers allows a dramatic reduction of the overall amount of electric power used for seawater desalination.

In most applications, a separate energy recovery system is dedicated to each individual SWRO train. However, some recent designs include configurations where two or more RO trains are serviced by a single energy recovery unit.

In 2005, a group of US federal and state agencies, public utilities and private desalination industry leaders formed the Affordable Desalination Collaboration (ADC). The team has taken up the challenge to design a SWRO plant aimed at achieving the lowest currently possible power demand using state-of-the-art pumping and energy recovery equipment and the latest membrane technology. They have installed a pilot SWRO plant at the US Navy's test facility in Pt. Hueneme, California and have operated this plant for a period of two years at various process configurations and performance set points. The results from this long-term testing show that potable water with salinity of less than 500 mg/L can be produced from Pacific Ocean water (salinity concentration of 33,500 mg/L/33.5 ppt) using less than 2.5 kWh/m^3 (9.5 kWh/kgal) of energy.

The main constraints today associated with achieving such low energy use in large-scale desalination plants are the quality of the product water in terms of boron, chlorides and bromides, and the efficiency of the available off-the-shelf pumps and motors used for source water collection, transfer and feed to the SWRO system. Often, the above-mentioned product water quality targets are driven by other, more stringent uses, such as irrigation of boron- or chloride-sensitive crops and ornamental plants, rather than by water quality requirements for human consumption. Achieving these goals requires the addition of one or more water quality polishing facilities after the main SWRO desalination process, which in turns increases the overall energy consumption for water production.

While the quest to lower energy use continues, there are physical limitations to how low the energy demand could go using RO desalination. The main limiting factors are the osmotic pressure that would need to be overcome to separate the salts from the seawater, and the amount of water that could be recovered from a cubic metre of seawater before the membrane separation process is hindered by salt scaling on the membrane surface and the service systems. This theoretical limit for the entire seawater desalination plant is approximately 1.2 kWh/m^3 (4.5 kWh/kgal).

Future technology advances

Key areas of development of RO membrane technology are associated with the increase in the productivity of the membrane elements, their resistance to fouling by the contaminants contained in the source water, and their durability and longevity. The quest for increased productivity of RO membrane elements has taken two directions: (1) development of larger diameter membrane elements and (2) incremental improvements in the SWRO membrane structure, chemistry, spacer size, and configuration which can allow more flow to be produced by a square inch of RO membrane area with reduced downtime for membrane cleaning.

Several years ago, researchers at the University of California-Los Angeles developed a new RO membrane which uses a cross-linked matrix of polymers and engineered nano-particles specifically designed to provide accelerated draw of water ions, while rejecting nearly all contaminants. The structure of existing RO membranes is such that the water molecules have to pass through a lengthy curvilinear path to reach the other side of the membrane. The matrix of the new membranes is structured at the nano-scale to create molecular tunnels which shorten and expedite water transfer, and thereby produce more fresh water per square of membrane. This new thin-film nano-composite RO membrane technology is projected to increase the productivity of membrane elements by 50-70% and to further reduce capital, operation and maintenance costs for water production. In addition, the new technology is expected to have lower fouling properties and repel organics, thereby reducing costs for membrane cleaning and energy use by 10-15% as well as increasing the useful life of the membrane elements.

Seawater cost trends

Advances in seawater RO desalination technology during the past two decades, combined with the transition to construction of large capacity plants, and enhanced competition by using the Build-Own-Operate-Transfer (BOOT) method of project delivery, have resulted in an overall downward cost trend. While the costs of production of desalinated water have benefited from the most recent advances in desalination technology, the cost spread among individual desalination projects observed over the past three years is fairly significant.

Most recently commissioned large seawater desalination projects worldwide produce desalinated water at an all-inclusive cost of US$0.8-1.5/m^3 (US$3.0-5.5/kgal). However, the traditionally active desalination markets in Israel and Northern Africa (i.e. Algeria) have yielded desalination projects with exceptionally low water production costs i.e. the SWRO plant in Sorek, Israel – US$0.53/m^3 (US$2.00/kgal) and the 87 MGD Hadera desalination plant in Israel – US$0.60/m^3 (US$2.27/kgal). On the other end of the cost spectrum, some of the most recent seawater desalination projects in Australia had been associated with the highest desalination costs observed over the past ten years, i.e., the Gold Coast SWRO plant in Queensland at US$2.90/m^3 (US$10.95/kgal) and Melbourne's Victorian desalination plant at US$2.52/m^3 (US$9.54/kgal).

While this extreme cost disparity has a number of site-specific reasons, the key differences associated with the lowest and highest-cost projects are related to five main factors:

Desalination site location

In the case of the above-referenced Australian desalination plants, the project sites were selected with a significant weight on 'not-in-my-back-yard' considerations. This resulted in project locations situated at an overly long distance (10-50 miles) from the points of delivery of the desalinated water into the water distribution system.

Environmental considerations

Similarly, there were problems locating desalination plant discharges for the referenced Australian desalination projects in the vicinity of marine species habitats with high sensitivity to elevated salinity. This resulted in the need to build complex concentrate discharge diffuser systems which costs in most cases exceeded 30% of the total desalination project expenditures. For comparison, most of the desalination plants yielding the lowest water production costs have concentrate discharges either located in coastal areas with very intensive natural mixing, or are combined with power plant outfall structures which use the buoyancy of the warm power plant cooling water to provide accelerated initial mixing and salinity plume dissipation at very low cost. The intake and discharge facility costs for these plants are usually less than 10% of the total desalination plant costs.

Phasing strategy

The desalination projects with highest and lowest costs have a very distinctive difference in terms of project phasing strategy. Large high-cost projects incorporate single intake and discharge tunnel structures built for the ultimate desalination plant capacity. Desalination projects on the low end of the cost spectrum use multi-pipe intake systems constructed mainly from high density polyethylene (HDPE) which have a capacity commensurate with the production capacity of the desalination plant.

Labour market pressures

Labour market differences can have a profound impact on the cost of construction of desalination projects. The overlapping schedules of the series of large desalination projects in Australia have created a temporary shortage of skilled labour, which in turn has resulted in a significant increase in unit labour costs. Since labour expenditures are usually 30-50% of the total desalination plant construction costs, a unit labour rate increase of 20-100%, could trigger sometimes unexpected and not frequently observed project cost increases.

Risk allocation

Without exception, the lowest cost desalination projects to date have been delivered under turnkey BOOT contracts where private sector developers share risks with the public sector based on their ability to control and mitigate the respective project related risks. ●

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